Detecting hidden hearing loss using the auditory steady state response

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Introduction

Background

- Hidden hearing loss = permanent neural damage resulting from noise exposure, but not reflected by the audiogram.
- In lab animals reflected by a reduction in auditory brain stem response (ABR) wave I amplitude in response to tone pips at moderate sound intensities (Kujawa and Liberman, 2009).
- In humans a correlation has been found between recreational noise exposure and ABR wave V-I amplitude (Stamper and Johnson, 2014) and possibly envelope-following response amplitude (Plack et al., 2014).
- Objective: develop an objective measure of hidden hearing loss in humans based on the auditory steady state response (ASSR).

Research questions

- What is the best stimulus and recording electrode combination to reliably measure ABR wave I amplitude?
- For which modulation frequency > 100Hz can the ASSR be reliably measured in most subjects?
- Do wave I amplitudes correspond to ASSR amplitudes?
- Are wave I amplitudes or ASSR amplitudes correlated with speech intelligibility or with a measure of recreational noise exposure?

Methods

Subjects

13 young normal-hearing (all thresholds better than 20 dB HL) subjects with no history of hearing problems

Subjective tests

- **Questionnaire**: Custom designed as to evaluate recreational noise exposure. Scored from 0 (minimal noise exposure) to 40 (maximal noise exposure).
- **Speech intelligibility**: Digit triplet test (Jansen et al., 2013) → speech reception threshold (dB)

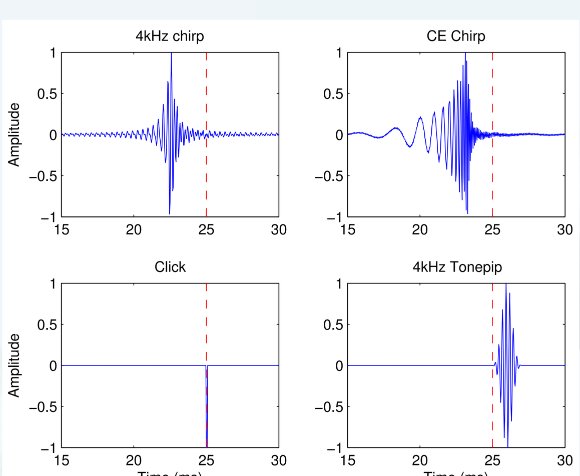
Apparatus

- 4 silver-chloride cup recording electrodes, at ipsi- and contralateral mastoid, forehead and collarbone, 1 ear-canal electrode (Etymotic TipTrode)
- Jaeger-Toenis amplifier, HP filter 2Hz
- Stimulation: Etymotic ER-3A insert phone, right ear

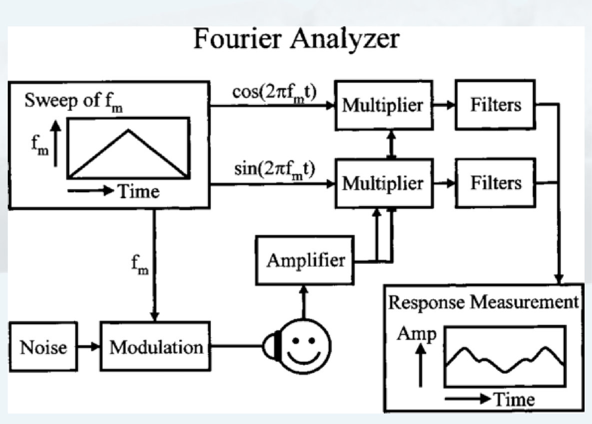
Auditory Brainstem Responses

Stimuli at 60 dB nHL (following threshold measurements), repetition rate 40 Hz, alternating polarity

- **Click**: 100 us click
- **4kHz Tone pip**: $F_c = 4$ kHz, 2-ms Blackman window
- **CE chirp**: 350-11300 Hz, frequency response of ER-3A compensated (Elberling et al., 2012)
- **4kHz chirp**: CE chirp filtered between 2828-5656 Hz
- **Analysis**: BP filtering 45-2500 Hz. Visual determination of peak I and V latency.



(a) ABR stimuli



(b) ASSR sweep analysis using Fourier analyzer. Figure from Purcell et al. (2004)

Auditory steady state responses - fixed AM

- Carrier: octave band noise around 4kHz
- Calibrated at 50 dB A
- Modulation frequency: 40 Hz and 275 Hz
- Duration 5-10 min per frequency
- Analysis: HT^2 test

Auditory steady state responses - sweeped AM

According to Purcell et al. (2004)

- Carrier: octave band noise around 4kHz
- Calibrated at 50 dB A
- Modulation frequency: linear sweep from 70-600 Hz (phase1) or 35-300 Hz (phase2)
- Duration: 15 s upsweep + 15 s downsweep
- Modulation depth: 100%
- ≈ 100 presentations of 30 s sweep
- Analysis: Fourier analyser, averaging window 1 s

References

Elberling, C., Kristensen, S.G.B., Don, M. (2012). Auditory brainstem responses to chirps delivered by different insert earphones. *J Acoust Soc Am*, 131(3), 2091–100.

Jansen, S., Luts, H., Dejonckere, P., et al. (2013). Efficient hearing screening in noise-exposed listeners using the digit triplet test. *Ear Hear*, 34(6), 773–8.

Kujawa, S.G., Liberman, M.C. (2009). Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *J Neurosci*, 29(45), 14077–85.

Plack, C.J., Barker, D., Prendergast, G. (2014). Perceptual consequences of "hidden" hearing loss. *Trends Hear*, 18.

Purcell, D.W., John, S.M., Schneider, B.A., et al. (2004). Human temporal auditory acuity as assessed by envelope following responses. *J Acoust Soc Am*, 116(6), 3581.

Stamper, G.C., Johnson, T.A. (2014). Auditory Function in Normal-Hearing, Noise-Exposed Human Ears. *Ear Hear*.

Results - subjective tests

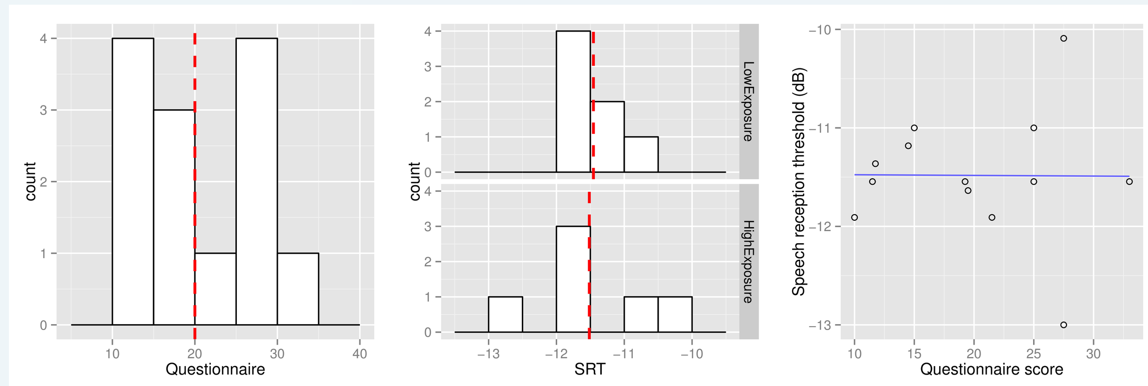
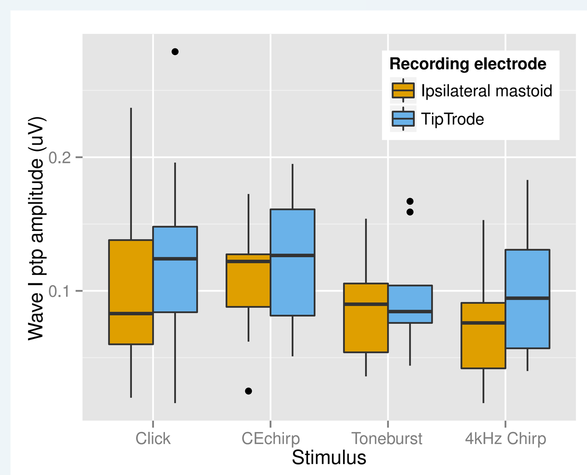
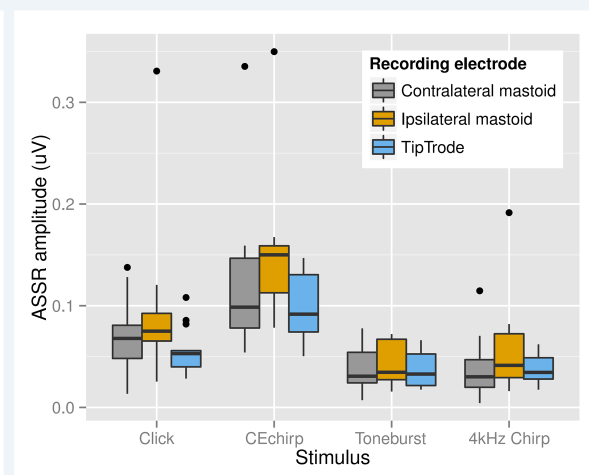


Figure 1: Questionnaire: bimodal distribution, divided into low (N=7) and high (N=6) noise exposure groups with threshold 20. No correlation was found between questionnaire scores and SRT.

Results - ABR



(a) Wave I peak-to-peak amplitude

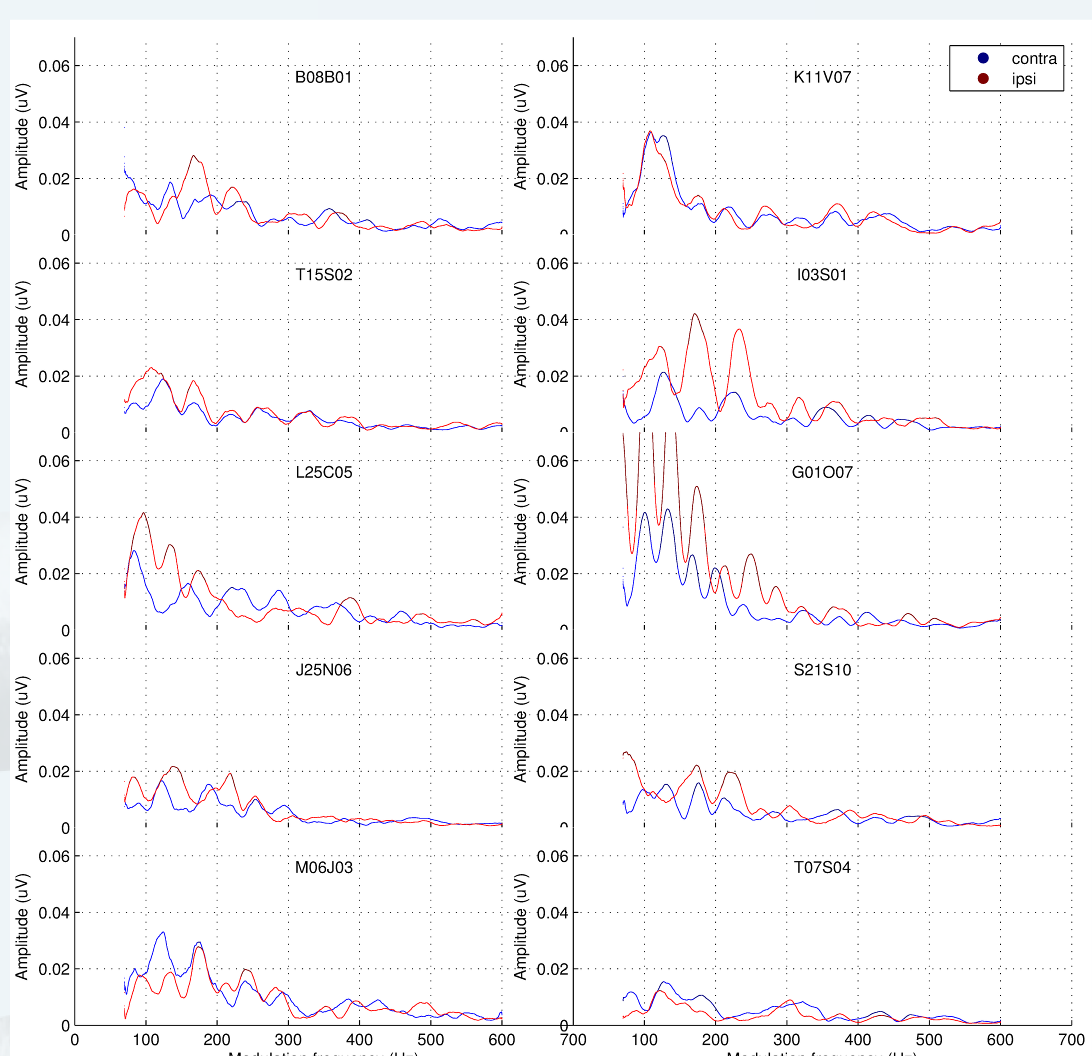


(b) 40-Hz ASSR amplitude for same stimulus

Figure 2: ABR and ASSR amplitudes

- ABR
  - Wave I reliably identified for ipsi and TipTrode (for 12/13 cases)
  - Significant effect of stimulus (Friedman rank-sum $\chi^2 = 10.57, p = 0.01$)
  - No significant difference between 4kHz Chirp and toneburst or CE chirp and click
  - TipTrode significantly better than ipsilateral (Wilcoxon test, $p < 0.01$)
- ASSR
  - Same effects + CE chirp significantly higher amplitude than click (Wilcoxon rank sum, $p < 0.01$)

Results - Sweeping ASSR



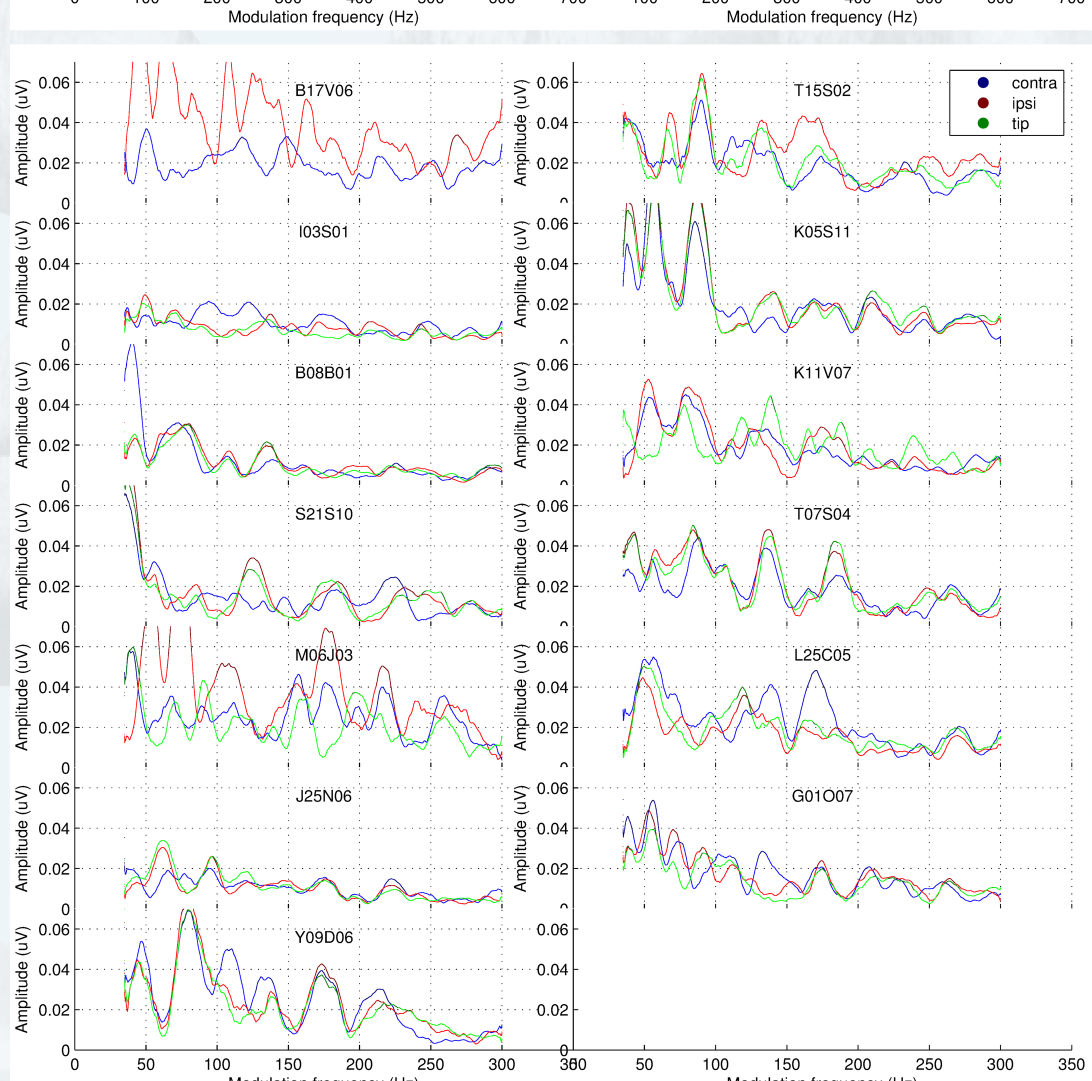


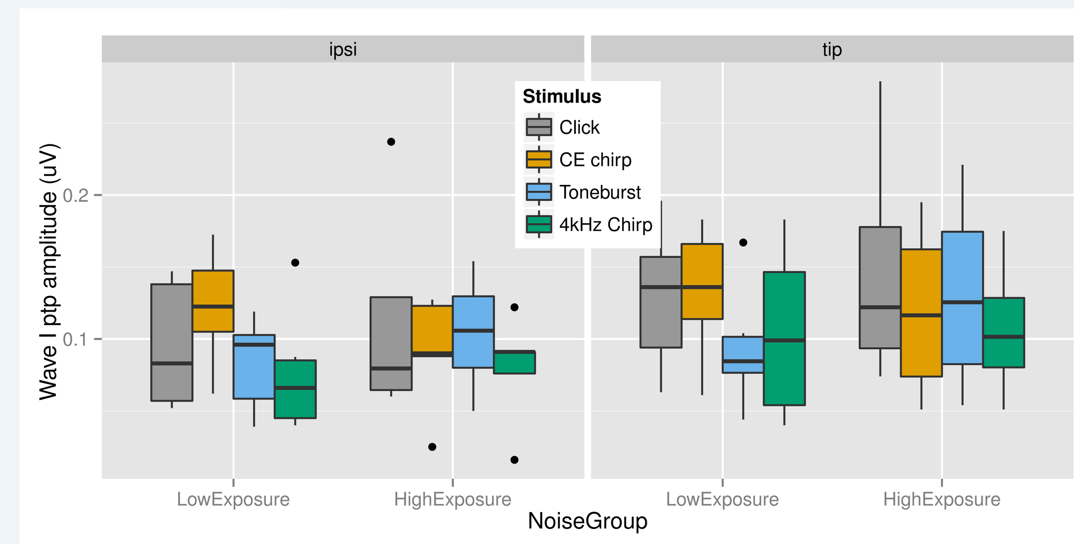
Figure 3: Sweeping ASSR results for phase 1 (70-600 Hz) and phase 2 (35-300 Hz). Significant responses (HT^2 test) are shown in darker colour.

- Different patterns across subjects
- Derived measures
  - For frequency ranges 35-55, 75-90, 150-250, and 150-300Hz
  - Surface under the curve for significant responses
  - Maximum amplitude

Group analysis

Spearman correlations were calculated between combinations of: questionnaire score, SRT, ABR wave I peak-to-peak amplitude, wave V peak-to-peak, V-I amplitude, and sweep surface or maximum in different ranges. Only marginally significant correlations were found, which disappeared after correction for multiple comparisons. Therefore subjects were divided in a low and high recreational noise exposure group and subsequent group analyses were conducted.

ABR



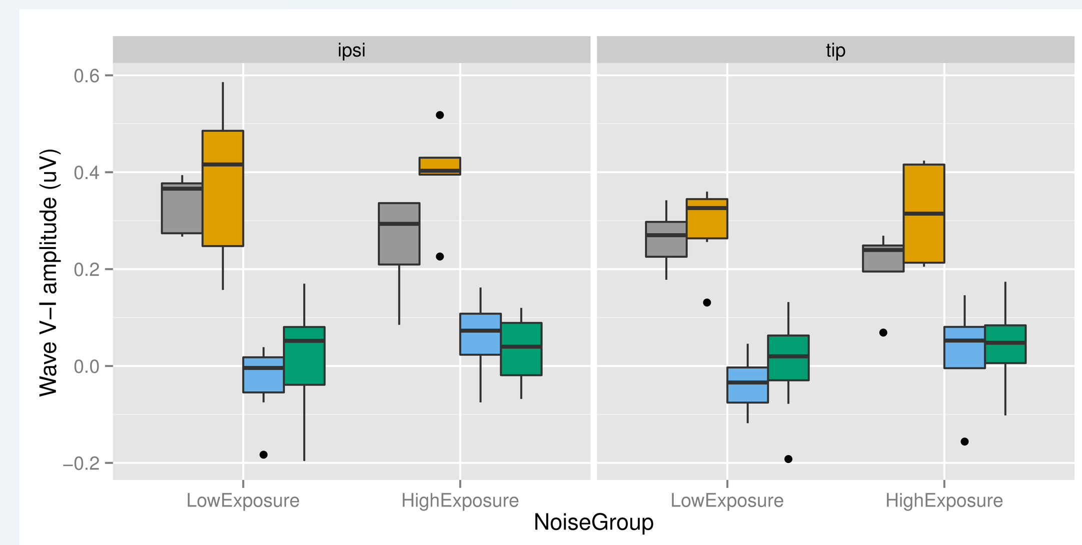


Figure 4: Wave I peak-to-peak amplitude and wave V-I peak amplitude per noise exposure group.

No significant differences found using paired Wilcoxon sign rank tests for each recording electrode and stimulus. Possibly due to difficulty of measuring wave I amplitude at low intensities. This is consistent with the results of Stamper and Johnson (2014), who also found no difference for lower intensities.

ASSR - fixed AM

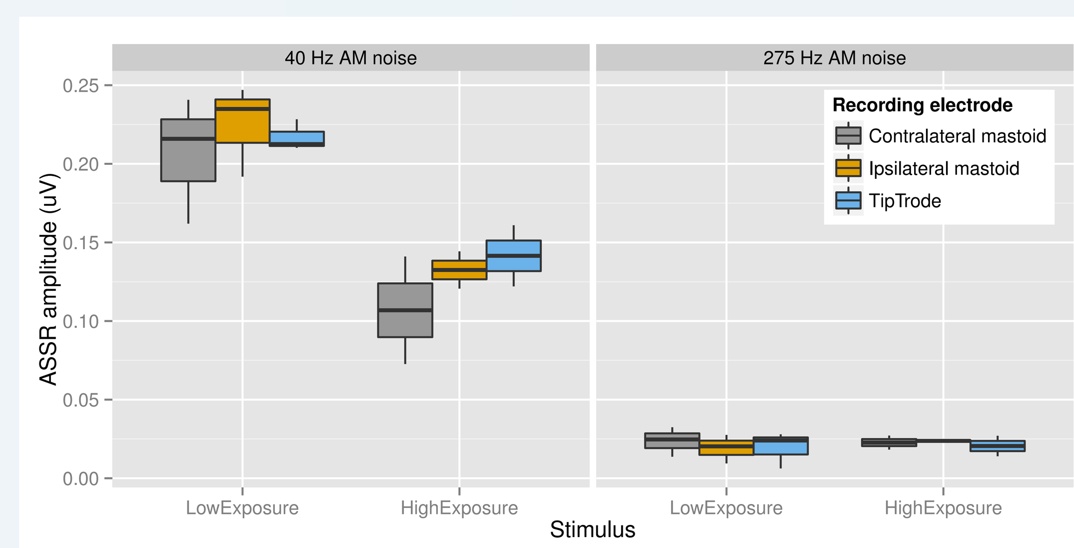


Figure 5: ASSR amplitude for fixed AM noise stimuli per noise exposure group.

Wilcox rank-sum test: significant effect of noise exposure group for FM=40 Hz (p<0.01), no effect for FM=275 Hz.

ASSR - sweeped

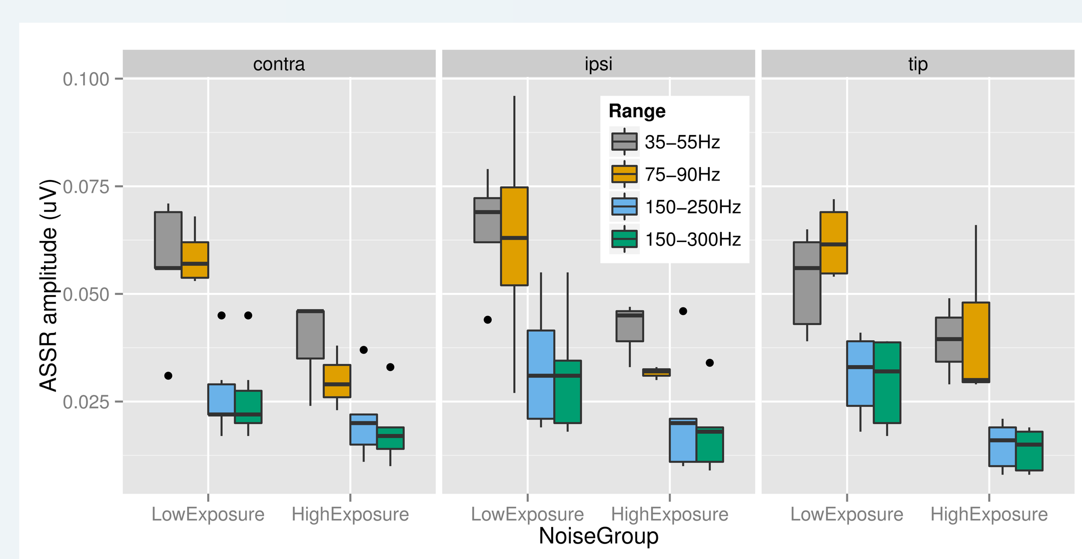


Figure 6: Average sweep amplitude across different frequency ranges, per noise exposure group.

Wilcoxon rank-sum significant for TipTrode/range 150-250 Hz ($p = 0.02$), and for TipTrode/range 150-300 Hz ($p = 0.04$), consistent with anecdotal evidence by Plack et al. (2014). Significance disappears with Holm correction for multiple comparisons.

Correspondence ABR / ASSR

No significant correlations were found between ASSR and ABR wave I related parameters, possibly due to the difficulty of measuring wave I amplitude at low intensities.

Conclusions

- Wave I could equally reliably identified using an ear-canal or mastoid electrode, but ear-canal electrode yielded significantly higher amplitudes.
- High-modulation frequency ASSRs could be most reliably measured in the range of 150-250Hz, but there was no single modulation frequency that yielded maximal amplitudes in all subjects.
- No significant correlations were found between questionnaire results, speech recognition thresholds, and ASSR amplitudes, nor between wave I amplitude and ASSR amplitude.
- There was a marginally significant difference between noise exposure groups in high-frequency ASSR amplitude in the range 150-250Hz.

Outlook: Tests with more listeners, different populations and at higher sound intensities are required to confirm the value of the high-frequency ASSR as correlate of hidden hearing loss.